High Performance Computing Based Simulation for Healthcare Decision Support

(2013.09 – 2016.07)

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INTRODUCTION

➢ Emergency Department (ED) is the main entrance to healthcare system, the Efficiency and Quality of Service (QoS) in ED has big influence to the whole healthcare system.

➢ Patients arrive the ED without prior appointment, some of them with unstable conditions and must be treated quickly!

➢ Some EDs are overcrowding and work with limited budget.

➢ ED is a complex system with many constraints!

➢ … …

Problems to solve

To make decisions to solve these problems, there are many questions should be answered first to support the decision, e.g.,

- If the number of arrival patients doubled, what will happen?
- If we increase 20 more careboxes, the overcrowding could be solved?
- The budget decreased, how QoS will be affected? which staff can be reduced? doctors? nurses? ... ?
- … …

How c Simulation ect of a decision without the commitment of any physical resources or interruption of the system?

My Agenda

- Introduction
- The Emergency Department Simulator
- Use of the Simulator
- Demo applications
- Conclusion and Future work

What is an ED simulator?

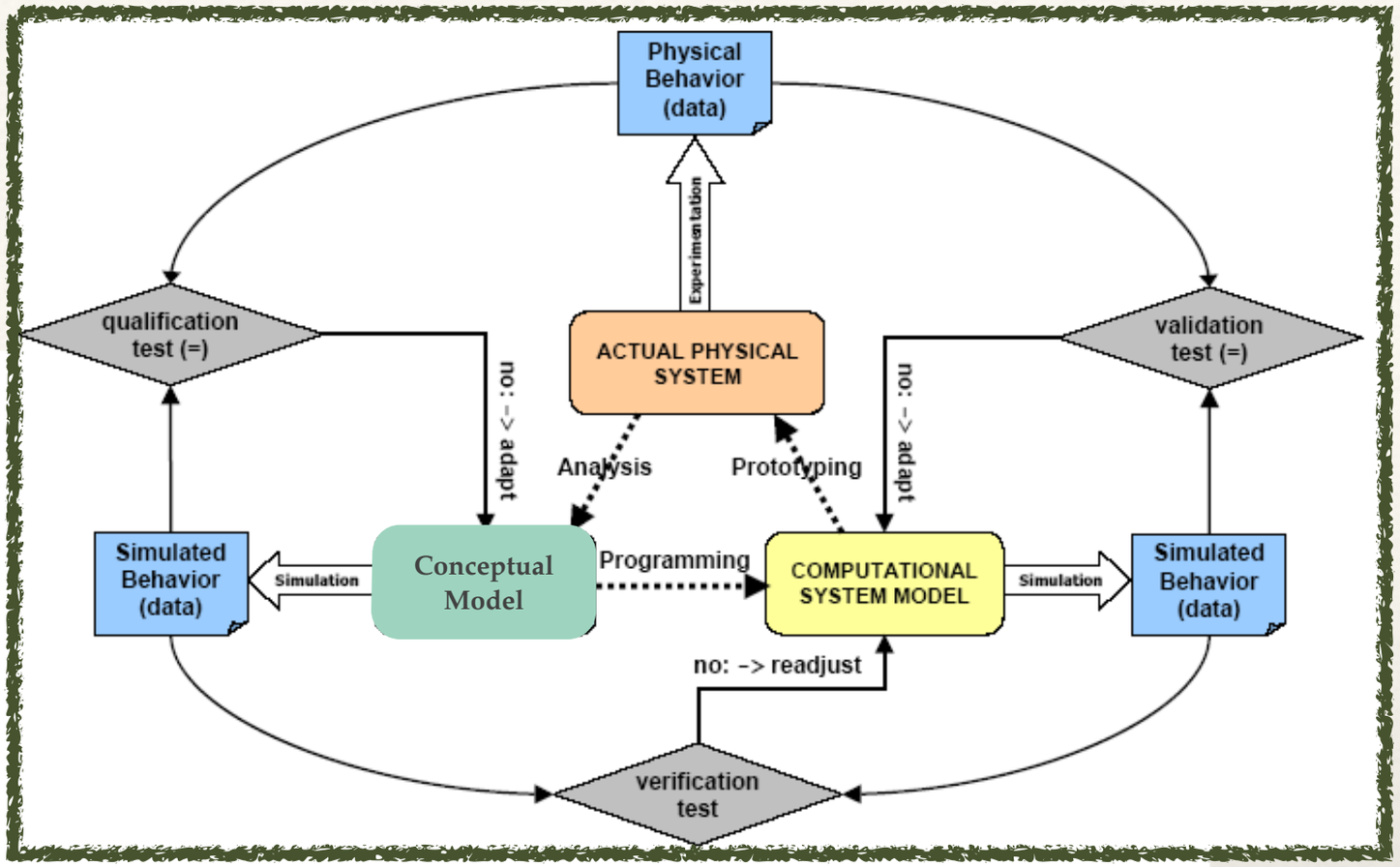
- Emergency Department:
  - Complex Adaptive System .
- Model:
  - Agent-Based Model;
  - Generalized and Adaptable.

A complex system is one in which there are multiple **interactions** between many different **components**, low-level interactions among components **emerge** collective high-level results.

Emergent Property: an observation about a system that we might not anticipate from the separate study of its individual components (Holland, 1998; Strogatz, 2003).

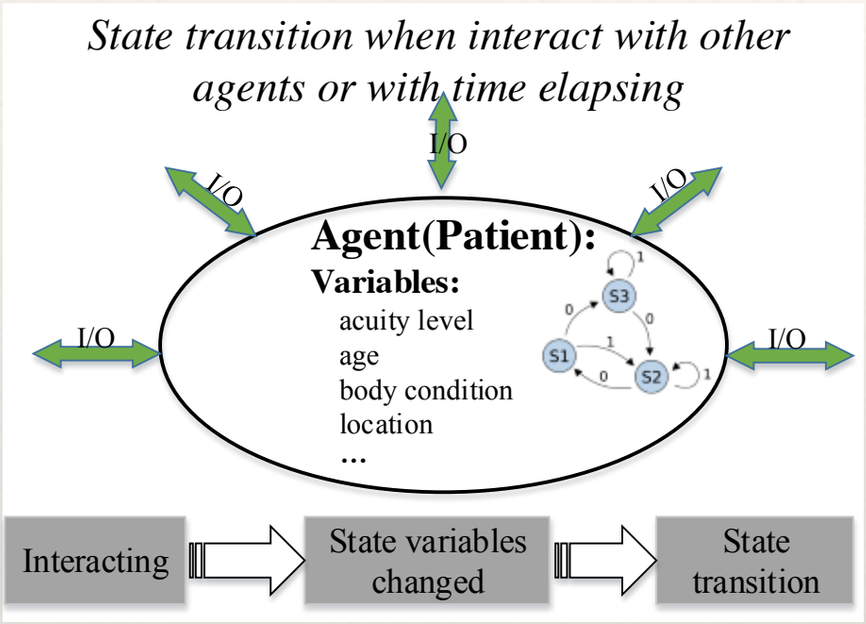
As the components of a system interact with each other, and influence each other through these interactions, the system as a whole exhibits emergent behavior (Roetzheim). This characteristic makes the output of a system difficult to understand and predict.

- Execution:
  - Model was implemented on Netlogo;
  - HPC is used to deal with the probabilistic agent model and study more scenarios in short time.

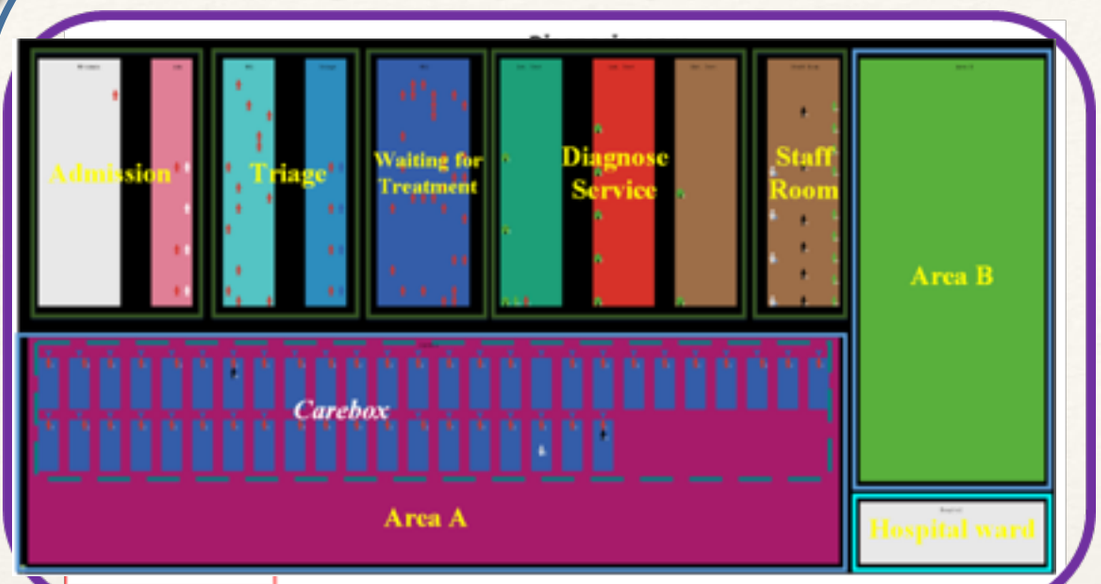


One Typical ED (Parc Tauli) in Spain for Model Verification

How it works?



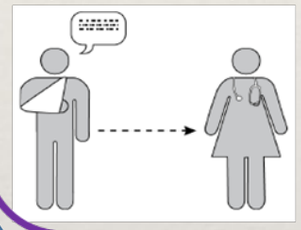
Emergency Departments



Active Agents
Patients
Companions of patients
Admission personnel
Sanitarian technicians
Nurses (Triage, Emergency)
Doctors (Emergency, Specialists)

Communication Model

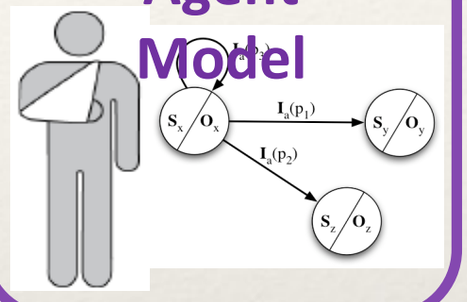
1 to 1
(One-to-One)



1 to n
(Multicast)

1 to Zone:
individuals in Zone
(Area- Restricted Broadcast)

Agent Model



Current state / Output	Input	Next state / Output
....	....	
Sx / Ox	Ia (p1)	Sy / Oy
Sx / Ox	Ia (p2)	Sz / Oz
Sx / Ox	Ia (p3)	Sx / Ox
....	....	....

Table 1: A part of a nurse's state transition.

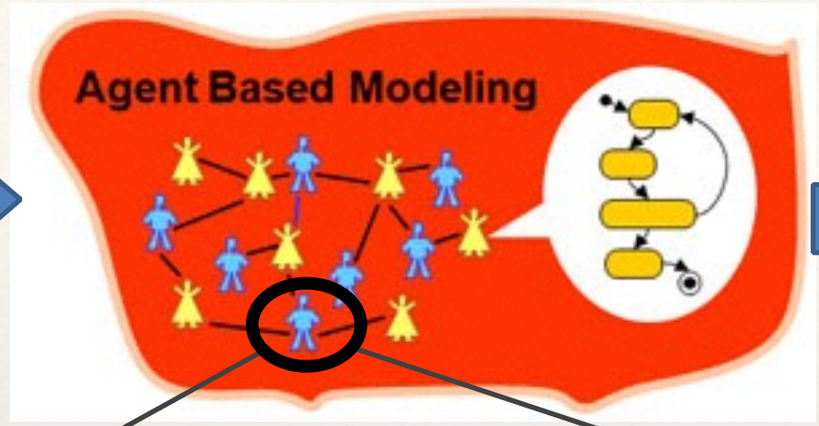
State index	Source State	Destination state	Input
...	...	...	...
S_t	Waiting for task.	Meet with patient(take blood sample).	blood test task from IS
S_{t+1}	Meet with patient.	Waiting for task.	sample take finished
S_{t+2}	Waiting for task.	Meet with patient(for treatment)	treatment task from IS.
S_{t+1}	Meet with patient.	Waiting for task.	treatment task finished
S_{t+3}	Waiting for task.	Meet with patient(help discharging)	Discharging task from IS.
...	...	...	...

How it works?

Patients

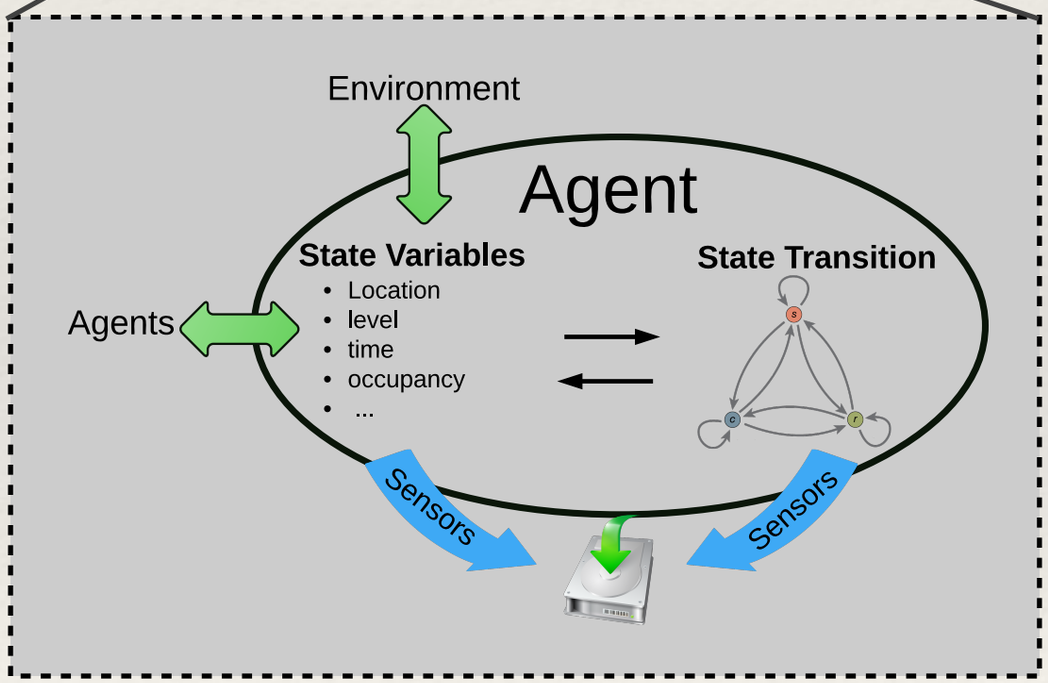
- Sanitary staff
- Physical Resources
- …

Configuration



Sensors

Interaction information



Reflect

Quantitative KPIs

ED Simulator

patient(input)

configuration

- ✓admission staff
- ✓triage nurse
- ✓nurse
- ✓doctor
- ✓auxiliary
- ✓carebox
- ✓laboratory test
- ✓internal test
- ✓external test
- ✓hospital ward
- ✓ambulance.
- ✓…

scenario

Resource	Capacity (#)		Avg. Attention Time (AT, minutes)		AT Distributic
	day	night	first interaction	follow-up	
junior admission staff	3	2	5		Gamma
senior admission staff	2	0	3		Gamma
junior triage nurse	3	1	8		Gamma
senior triage nurse	2	1	6		Gamma
junior doctor in area A	2		20	15	exponential
senior doctor in area A	4		15	13	exponential
junior nurse in area A	5		25	18	exponential
senior nurse in area A	5		20	14	exponential
junior doctor in area B	2		8	7	exponential
senior doctor in area B	5		6	5	exponential
junior nurse in area B	4		11	7	exponential
senior nurse in area B	4		7	5	exponential
medical imaging test room	5	2	45		Beta
laboratory test place	4	2	30		Beta
carebox in area A	50		-		-
chair in area B	60		-		-
auxiliary nursing staff	3		15		exponential

Statistical Model

Should Execute Many Times for One Scenario

acuity level: 1 → 5

Patient:

Scenario = ED-Model-Configuration + Input (Patient)

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Application Framework for Knowledge Discovery

Simulator User, to discover macro-level system features

Macro Level Simulator(Application)

Data Process Layer(Adaptation)

Monitoring Layer(Sensor)

Micro Level Simulator
(Agent Based Model)
[**Core**]

Abstraction Path

configurable

requirement

oriented

simulation scenarios[s1, s2, s3...]

Set Scenario(s) → Simulate → Analysis → KPIs

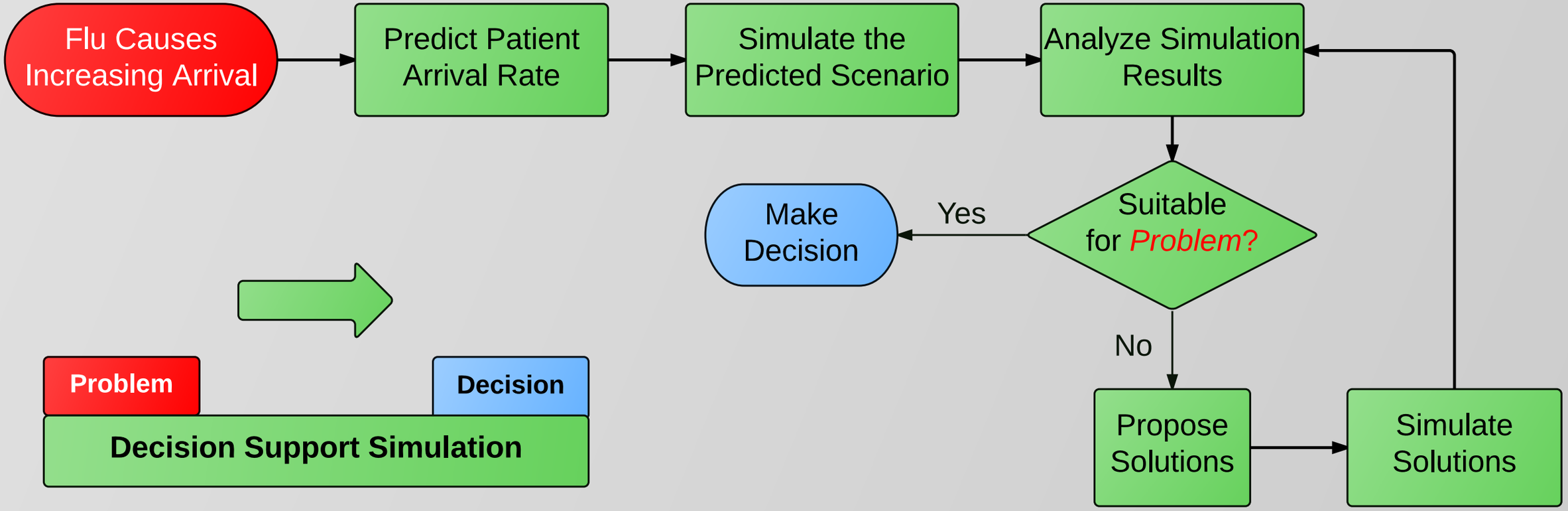
Design of Experiments

Interaction Info.

Predictions

Demo application

Decision Support for Continuously Increasing Patients Arrival



Scenario

INPUT OF SIMULATOR

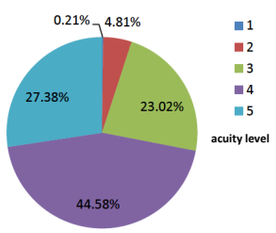
Simulation condition:

Simulated Time: 720 hours (30 days)

Execution Time: 5 minutes per one scenario one core

Input

Real Data from Hospital of Sabadell



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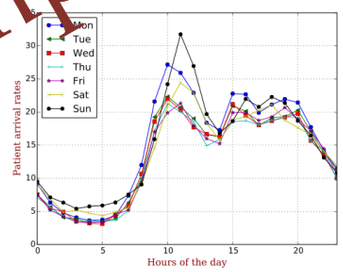
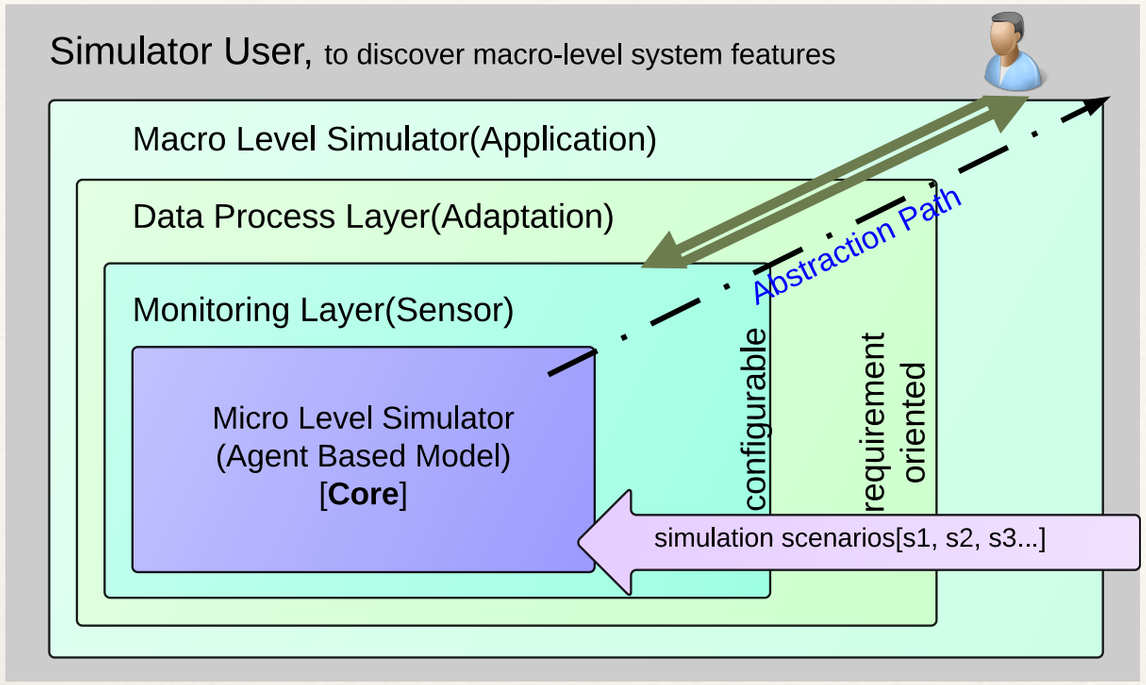


361 patients / day

+

Configuration

Resource	Capacity (#)		Avg. Attention Time (AT, minutes)		AT Distributic
	day	night	first interaction	follow-up	
junior admission staff	3	2	5		Gamma
senior admission staff	2	0	3		Gamma
junior triage nurse	3	1	8		Gamma
senior triage nurse	2	1	6		Gamma
junior doctor in area A	2		20	15	exponential
senior doctor in area A	4		15	13	exponential
junior nurse in area A	5		25	18	exponential
senior nurse in area A	5		20	14	exponential
junior doctor in area B	2		8	7	exponential
senior doctor in area B	5		6	5	exponential
junior nurse in area B	4		11	7	exponential
senior nurse in area B	4		7	5	exponential
medical imaging test room	1		45		Beta
laboratory test place	4	2	30		Beta
carebox in area A	50		-		-
chair in area B	60		-		-
auxiliary nursing staff	3		15		exponential



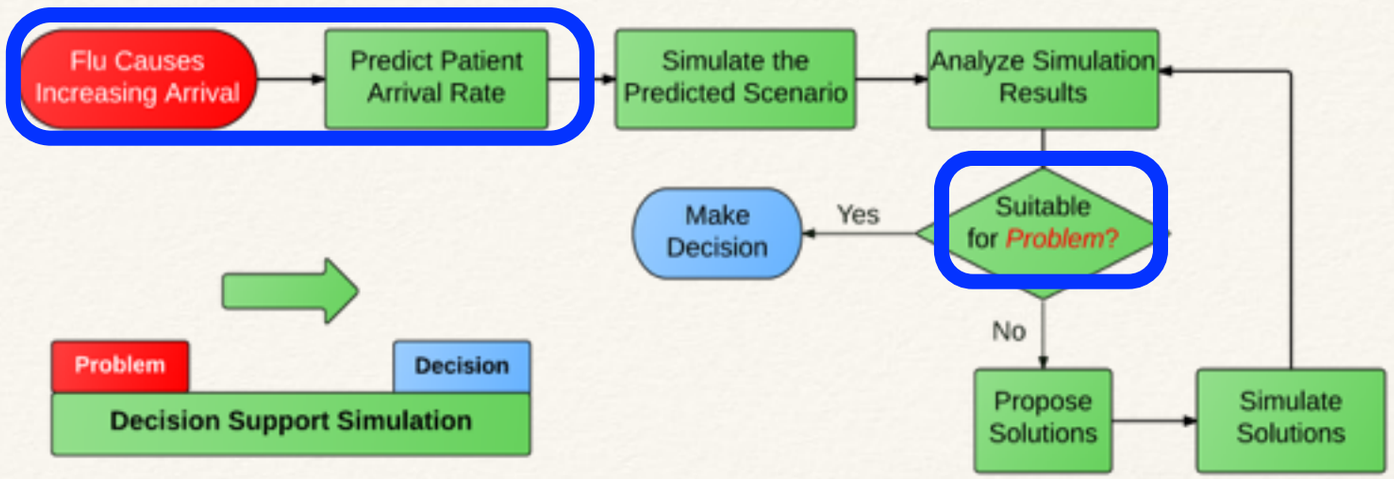


Table 1: LoS and ED resources utilization with increasing arrival patient

Daily arrival	Average LoS by acuity level(hour)					Average utilization of ED resources(%)				
	1	2	3	4	5	Tr_{lab}	N_A	D_A	D_B	N_B
361	10.83	10.30	9.79	3.01	2.81	70.51	40.57	67.94	53.95	43.68
397	10.84	10.90	10.41	3.43	3.81	81.39	46.31	78.29	62.05	50.27
416	11.66	11.28	10.69	3.59	4.12	83.64	48.01	80.59	64.23	52.16
436	11.87	11.73	11.31	3.78	5.28	86.75	50.01	84.50	66.84	54.17
456	11.71	12.09	11.85	3.98	**8.94**	**91.32**	51.85	87.19	69.80	56.27

Add two more technicians to laboratory room

Daily arrival	Average LoS by acuity level(hour)					Average utilization of ED resources(%)				
	1	2	3	4	5	Tr_{lab}	N_A	D_A	D_B	N_B
456	11.58	11.90	11.70	3.65	**3.17**	**60.67**	51.99	87.19	69.47	56.65
476	12.54	12.70	14.33	3.80	3.57	64.19	55.04	92.30	73.01	59.42
496	13.23	12.90	**33.93**	4.02	4.16	66.37	56.90	**96.06**	76.32	62.25

Final Decision:
add Two Laboratory **Technicians**
and
Two **Doctors** to area A

Table 1: Two more doctors added to area A

Daily arrival	Average LoS by acuity level(hour)					Average utilization of ED resources(%)				
	1	2	3	4	5	Tr_{lab}	N_A	D_A	D_B	N_B
496	10.89	11.01	**11.07**	3.98	4.15	66.73	57.50	**71.84**	75.79	61.58
516	11.12	10.86	11.20	4.13	4.79	68.75	58.67	72.99	78.80	64.30
535	11.26	11.31	12.54	4.36	5.82	71.39	60.65	76.00	82.52	67.14

Other Analyzed Cases

- ✓ Cross-scenario analysis to **explore** the effect of configurations.
- ✓ Influence of **Ambulance** Service for Departure (one way to relieve overcrowding in real situation);
- ✓ Single Scenario Analysis to **Full Insight** into the System Dynamics (from Micro-to-Macro, Root-Cause Analysis).

Developed Work:

(1) Created A Generalized Agent-Based Model for ED;

(2) Implemented and Verified the ED Simulator;

(3) Implemented the Configurable Meta-Data Sensors;

(4) Proposed a Knowledge Discovery Framework;

(5) 2 Publications (SIMUL 2014 and ICCS 2015).

Further Contributions:

(1) Global Sensitivity Analysis;

(2) Automatic Calibration;

Thanks for Your Attention!

¡Gracias a todos por todo!

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